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HSCT INLET DEVELOPMENT ISSUES

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SUPERSONIC INLET INTEGRATION ISSUES

The purpose of this presentation is to highlight the issues affecting the development of engine air inlets for the HSCT. The Propulsion Airframe Integration Technology (PAIT) contract (NAS3-25963) sponsored by NASA Lewis Research Center is an important element in the evolution of the propulsion system that will eventually power the HSCT. Most of the material presented here is based on work performed by The Boeing Company under Tasks 1 and 2 of PAIT.

From the propulsion perspective the premier technology issues associated with the HSCT are airport noise and high altitude emissions. The sources are the nozzle and combustor, respectively. For the inlet the most challenging issues are associated with integration, these include the following:

- *Integration with the main landing gear:* protection from FOD, and water and slush ingestion from the runway;
- *integration with the engine:* ensuring engine/inlet airflow matching, normal shock stability during engine airflow transients, and keeping total pressure distortion within acceptable limits;
- *integration with the wing:* minimizing nacelle/wing interference drag and inlet flowfield velocity distortion.

Inlet/Airframe Integration Issues

LOW SPEED

- FOD, water/slush ingestion
- noise suppression
- auxiliary inlets

TRANSONIC/SUBSONIC CRUISE

- engine/inlet airflow matching
- spillage drag
- wing/nacelle interference drag

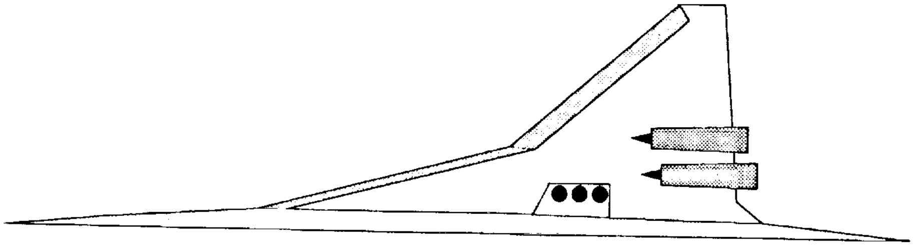
SUPERSONIC CRUISE

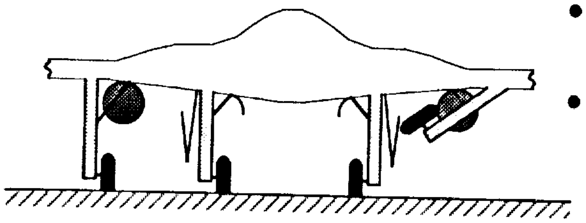
- wing/nacelle interference drag
- normal shock stability

LANDING GEAR/INLET INTERFERENCE

Nacelle locations dictated by the slender wing planform and the need for the nozzles to be near the wing trailing edge may expose the inlets to the wake of the main landing gear. In addition to shed vortices, the wake could carry runway debris. The integration must minimize the hazards of foreign object damage (FOD) to the inlet and the engine. The inlet must also be kept out of the landing gear's water and slush spray pattern when operating on wet runways. Ingestion of excessive water and/or slush could result in degraded compressor performance. Selection of the nacelle locations is a crucial issue.

LANDING-GEAR/INLET INTEGRATION



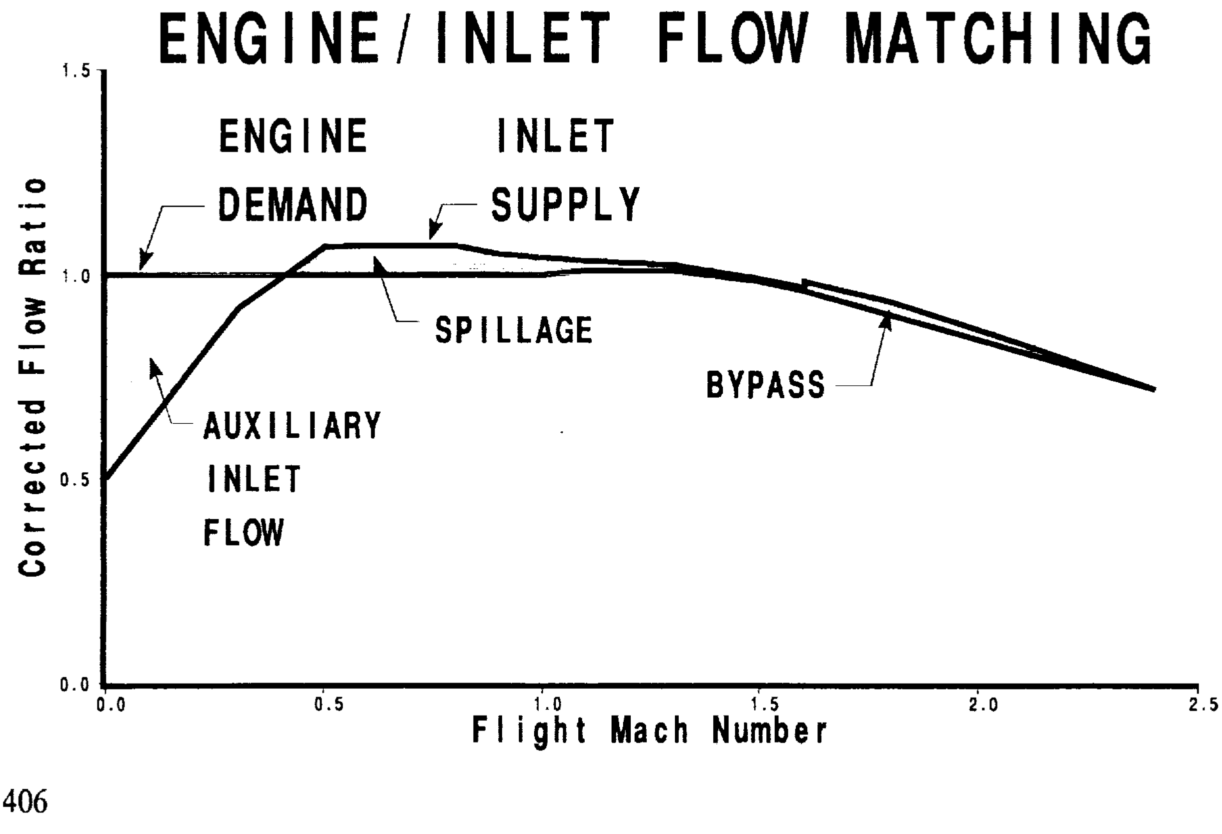


- Inlets away from leading edge.
- Nozzles near wing trailing edge.
- Propulsion nacelles close to airplane centerline.
- Inlets vulnerable to runway debris and slush spray from wheels.

INLET/ENGINE COMPATIBILITY

The inlet is typically sized to match the engine demand at the top of climb (i.e. the beginning of cruise) so as to minimize cruise drag. The engine may be sized at a different point in the mission (e.g. takeoff, transonic climb, etc.) depending on the thrust requirements of the airplane. The design of both the inlet and of the engine must take into account the need for a close match between the inlet supply and the engine demand airflows. The inlet must be designed to limit the level of total pressure distortion and the engine must tolerate a reasonable level of distortion.

Mixed compression inlets must tolerate minor fluctuations in engine airflow demand without unstarting. The propulsion control system must be able to deal with larger disturbances.



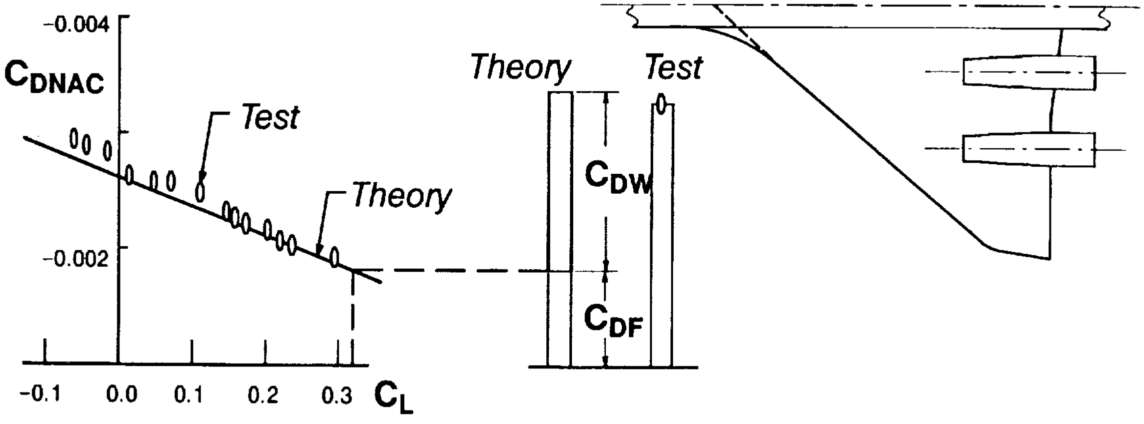
NACELLE/WING INTERFERENCE

Performance of supersonic inlets, especially of the mixed compression variety, is sensitive to Mach number gradients in the local flowfield. The wing must be contoured to minimize such gradients. But since the flow will not be perfectly uniform, the inlet must tolerate some levels of non–uniformity.

The wing and nacelle flowfields are closely coupled. The interference forces are significant. The complex aerodynamic forces cannot be eliminated completely, so they must be put to best advantage. The figure shows that if the wing and nacelle are properly shaped, the pressure field of the nacelle shock wave can be used to pressurize the aft facing area of the lower wing. The net result is that the installed drag of the nacelle is equal to its skin friction drag, the wave drag having been cancelled by the thrust force on the wing.

NACELLE/WING INTERFERENCE

- **Wing shape, nacelle shape, nacelle position.**
- **Proper combination reduces installed drag to level of skin friction.**



Installed Drag **Isolated Drag**

INLET DEVELOPMENT PLAN

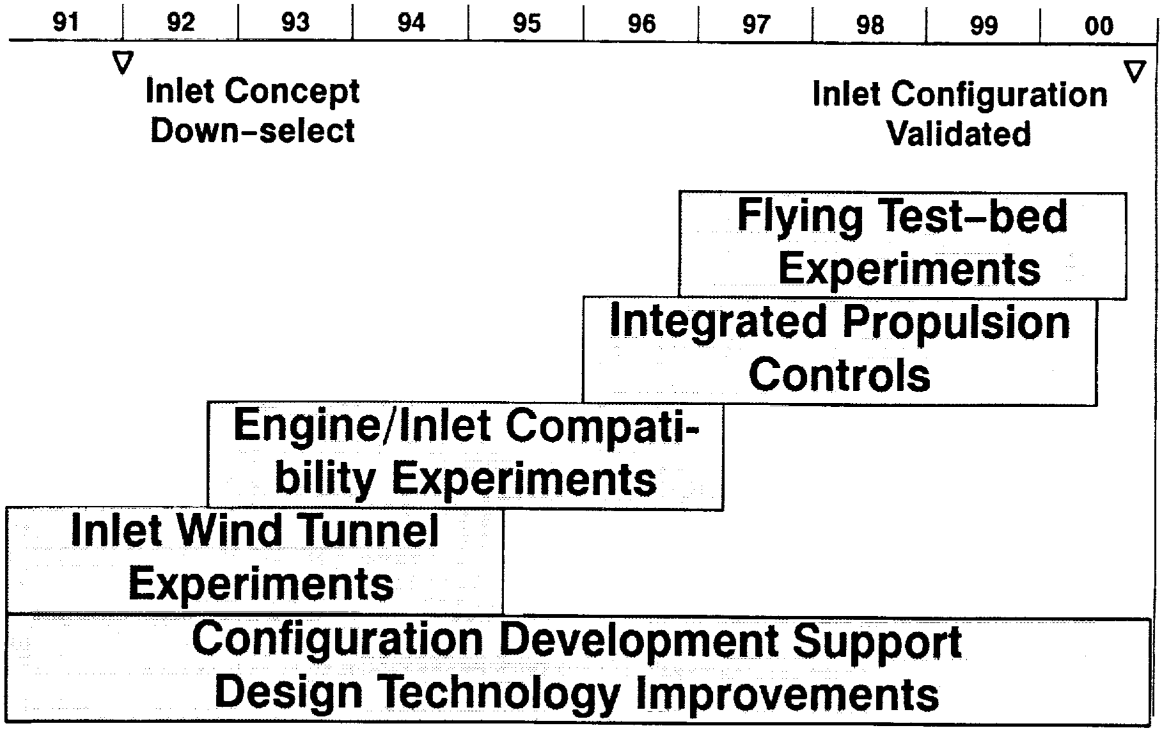
The HSCT inlet development plan is built on a foundation of continued design technology enhancements. Elements of the effort under way include: broadening the applications of CFD, expanding the inlet boundary layer control bleed system data base, and refining drag analyses, especially in the transonic speed regime.

Throughout the inlet development program support must be provided to development of the vehicle configuration. This effort includes prediction of the installed performance of various inlet designs so that the design trade studies will lead to the optimum integration.

At the present state of CFD the theoretical predictions must be validated in wind tunnel tests. Testing usually begins with cold flow inlet models. When the performance of the inlet is understood and accepted, compatibility of the inlet and engine must be established. In addition to verifying the aerodynamic compatibly of the propulsion system components, the compatibility experiments validate the viability of the propulsion control system.

NASA Lewis Research Center is actively supporting the development of the inlet for the HSCT through the Propulsion Airframe Integration Technology contract (NAS3-25963).

HSCT INLET DEVELOPMENT PLAN



PAIT PROGRAM OBJECTIVES

The overall objective of the Propulsion Airframe Integration contract (NAS3-25963) is to identify the best inlet for an HSCT having a cruise Mach number in the range of 2.0 to 2.5. The figures of merit used in making the final selection should reflect the impact of the choice on total mission performance.

NASA's participation can supplement industry's efforts by pursuing concepts that have a potential for high payoff with perhaps higher technical risk. The initial tasks of the PAIT contract comprise analytical studies to narrow the field of competing inlet concepts. Based on the results of the initial assessment, one or more concepts will be recommended for further research. The follow-on work is expected to include wind tunnel testing of the selected inlets first alone and later coupled with engines.

PAIT Program Objectives

Propulsion Airframe Integration Technology

Contract No. NAS3-25963

- **Select HSCT inlet concept for cruise Mach number in range of 2.0 to 2.5.**
- **Design inlet for safety and efficiency.**
- **Integrate inlet design with airframe.**
    - **prevent engine FOD**
    - **minimize cruise drag**
    - **reduce community noise**

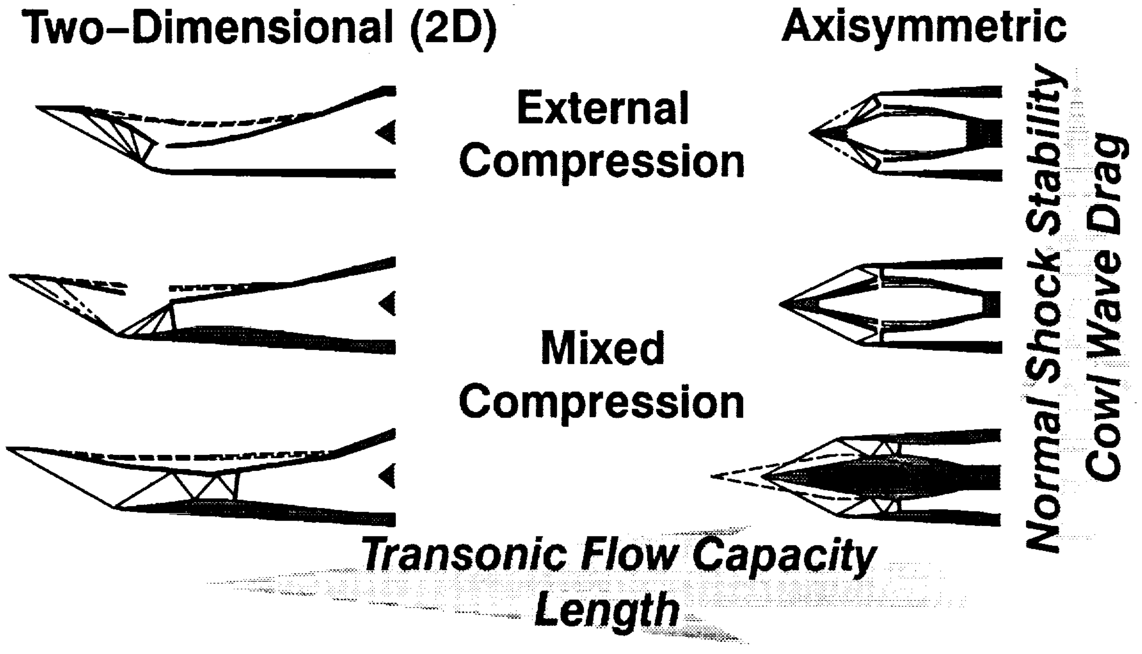
INLET CONCEPTS FOR PAIT

Currently six inlet concepts are being studied under Tasks 1 and 2 of the Propulsion Airframe Integration contract (NAS3-25963). All of the inlets are designed for Mach 2.4 cruise flight. The reference engine airflow schedule for the studies is that of a turbine bypass engine proposed by P&WA for the HSCT. The concepts were picked to assess the benefits of 2D versus axisymmetric and external vs mixed compression designs. In both the 2D and axisymmetric groups, two mixed compression concepts are shown. The ones in the center have more external compression and shorter internal supersonic diffuser, while the ones at the bottom have less external compression and longer supersonic diffusers.

The stability of the normal shock tends to increase as more compression is done externally. At the same time the wave drag of the external cowl tends to increase. Two-dimensional inlets generally require more length than axisymmetric designs. In compensation, they offer more versatility in flow supply schedule and integration. The final selection is likely to be based on the requirements of integration.

INLET CONCEPTS FOR PAIT

NAS3-25963


Two-Dimensional (2D)

Axisymmetric

External Compression

Mixed Compression

Normal Shock Stability

Cowl Wave Drag

Transonic Flow Capacity

Length

PAIT INLET SELECTION CRITERIA

Tasks 1 and 2 of the Propulsion Airframe Integration contract (NAS3-25963) are under way. The analytical screening studies under the first task compare the inlets on the bases of internal performance, maximum flow supply capacity, boundary layer bleed requirements, and isolated (without wing) drag. The effort comprises definition of the inlet contours and prediction of inlet performance using CFD and lower order analyses.

Under the second task, designs studies are in progress to compare the candidate inlets on the basis of weight. The designs are carried to sufficient detail to allow structural sizing of components.

The objective of the third task is to compute the effects of the same inlets on vehicle mission performance.

PAIT INLET SELECTION CRITERIA

Task 1

ISOLATED INLET PERFORMANCE

- Total pressure recovery
- Cruise boundary layer bleed drag
- Transonic spillage drag

Task 2

INLET WEIGHT

Task 3

AIRPLANE MISSION PERFORMANCE

PRELIMINARY DESIGN AND ANALYSIS TOOLS

The initial steps for translating the inlet concepts into specific designs were accomplished using procedures developed during the Boeing SST and SCR programs. Once satisfactory results were obtained with the design codes, further computational fluid dynamics analyses were conducted using the PARC code.

The supersonic diffuser lines were generated iteratively applying Boeing's method–of–characteristics code. The predicted pressure profiles were analyzed with a finite difference boundary layer code to determine the locations and flowrates of boundary layer bleed required to prevent separation.

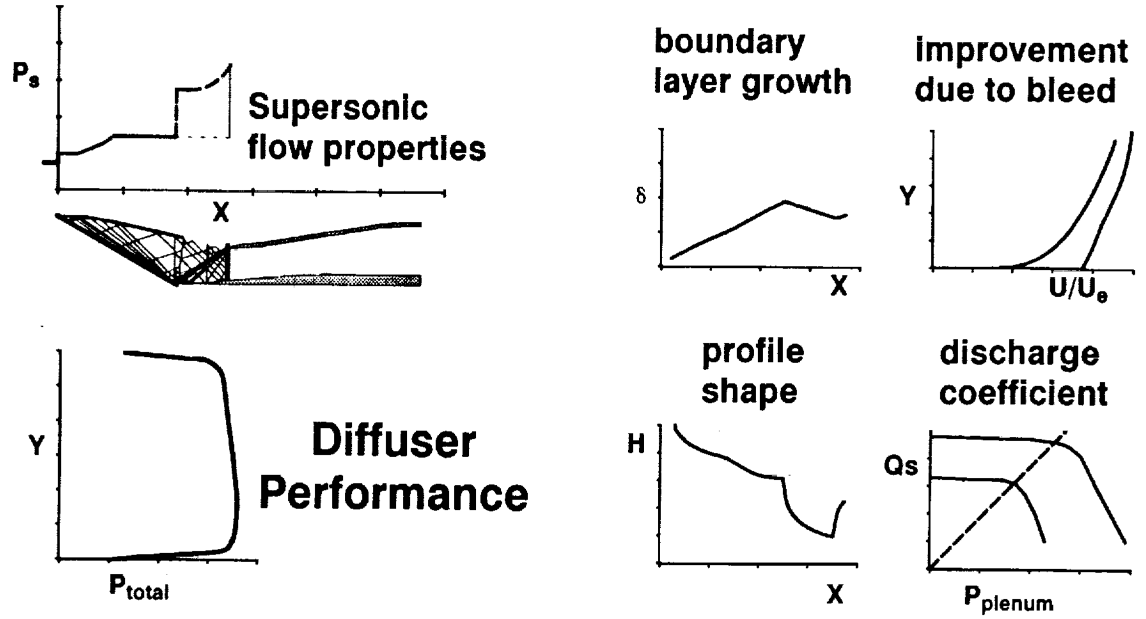
The normal shock total pressure losses were calculated from the predicted supersonic Mach number profiles at the inlet throat. The subsonic diffuser performance was estimated with a code developed at Stanford University and modified at Boeing. The code allows for interactions between the boundary layer and the core flow through an entrainment function.

The design codes (method–of–characteristics, boundary layer, subsonic diffuser) were run on engineering work stations with typical execution times measured in seconds. This procedure allowed preliminary analyses of a large number of trial contours.

PRELIMINARY DESIGN/ANALYSIS

Method of Characteristics

Boundary Layer Analysis



CFD ANALYSES

The PARC code was run in the 2D/axisymmetric Euler mode to analyze the flowfields of the inlets generated with the design codes. Various flight conditions were simulated. The parameters varied included flight Mach number and engine corrected flow.

The objectives were to confirm the results of the preliminary analyses. The PARC computations include the complete flowfield from the undisturbed freestream to the engine face as opposed to the zone-by-zone analysis approach of the design codes. The effects of oblique and normal shock waves are detailed, allowing determination of the shape and operating position of the normal shock. More significantly, in the unstarted supersonic operating mode, the sensitivity of spillage drag to normal shock spillage flowrate can be directly calculated. Boundary layer effects are not included in the Euler solutions since viscosity is not simulated.

Sample results from the CFD analyses are presented in the following charts.

CFD APPLICATIONS

PARC CODE

- 2D/Axisymmetric
- Euler mode (no viscosity)

RESULTS

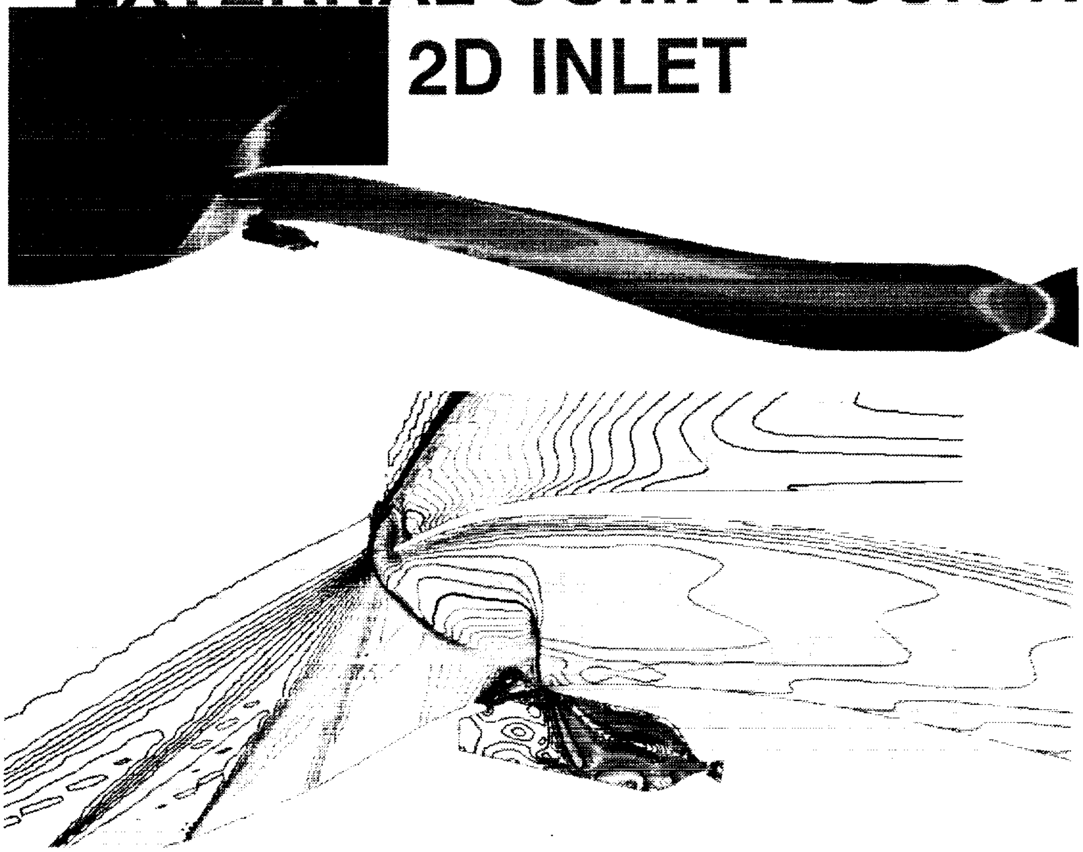
- Normal shock position and shape
- Combined oblique and normal shock losses
- Transonic spillage drag

EXTERNAL COMPRESSION 2D INLET

The first concept in the inlet matrix is derived from a model tested in the Lewis 10- by 10-ft supersonic wind tunnel in 1986 (NASA CR 182253). The upper part of the chart shows the computation domain of the PARC CFD analysis. The engine face is located at approximately the midpoint of the long subsonic duct. The extension downstream of the engine face was provided to allow the flow profile to be non-uniform at the engine face. Variations in engine power setting were simulated by varying the throat area of a choked convergent-divergent nozzle at the end of the flow duct.

The lower part of the chart shows a close-up of the inlet aperture region. The flow out of the throat slot plenum is also controlled by a choked nozzle. The black lines trace the sonic lines. The aperture region contains a complex flowfield comprising supersonic flow with oblique shock waves, normal shocks, subsonic flow, and a free shear layer dividing the stagnant air in the plenum from the primary flow. The CFD results were valuable in shaping the contours of the aperture. The lower order codes are of little help in describing the details of the flow in this region.

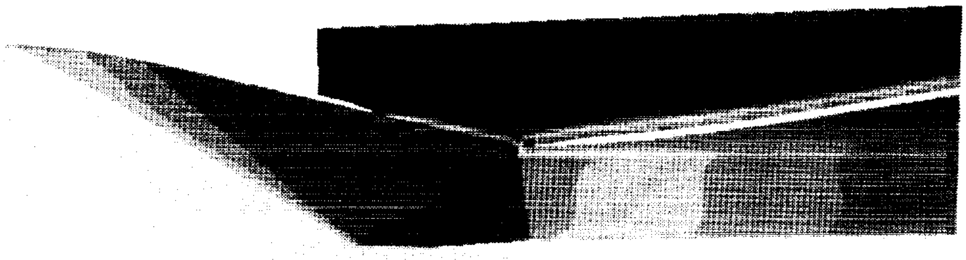
EXTERNAL COMPRESSION
2D INLET



TWO-STAGE SUPERSONIC INLET

The second concept in the inlet matrix incorporates a long unbounded surface and a plenum upstream of the throat. The appearance is that of a mixed compression inlet with one ramp missing. Unique features of the concept include the following: 1) the cowl lip shock and the distributed cowl compression are focused at the leading edge of the aft ramp so that no compression is taking place over the free surface of the plenum; 2) the normal shock is positioned just upstream of the aft ramp's leading edge, a relationship similar to that of the normal shock and cowl in an external compression inlet; 3) the normal shock position is controlled by closed loop control of the plenum pressure through control of the plenum exit area. Maintaining a constant static pressure in the plenum allows for the spillage of subsonic flow at various rates without affecting the supersonic diffuser flowfield. The spillage flow shows up as a thin jet adhering to the upper surface of the aft ramp in the figure.

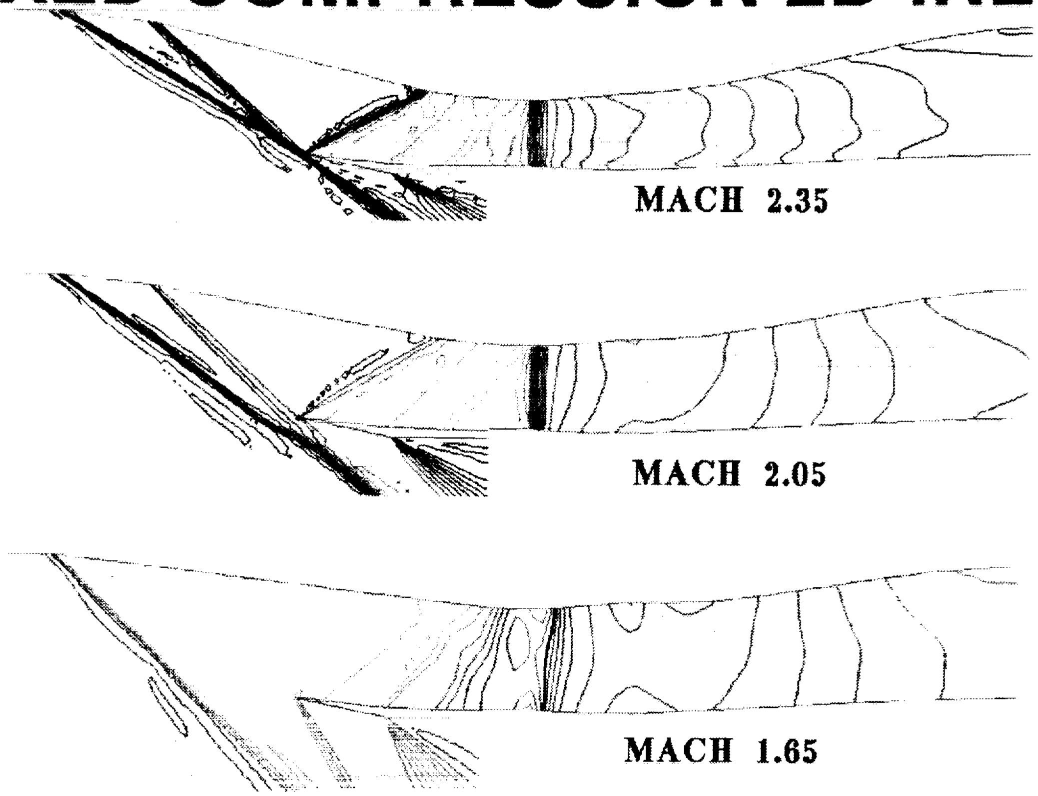
TWO-STAGE SUPERSONIC INLET



MIXED COMPRESSION 2D INLET

Results of CFD analyses are shown for a more conventional type of mixed compression 2D inlet. The design incorporates three movable ramps and has a much longer supersonic diffuser than the previous inlet. The throat Mach number is maintained at 1.25 to provide tolerance to small fluctuations in freestream Mach number. The normal shock is positioned just downstream of the throat where the Mach number is about 1.3. This provides tolerance to minor fluctuations in the engine flow demand.

MIXED COMPRESSION 2D INLET

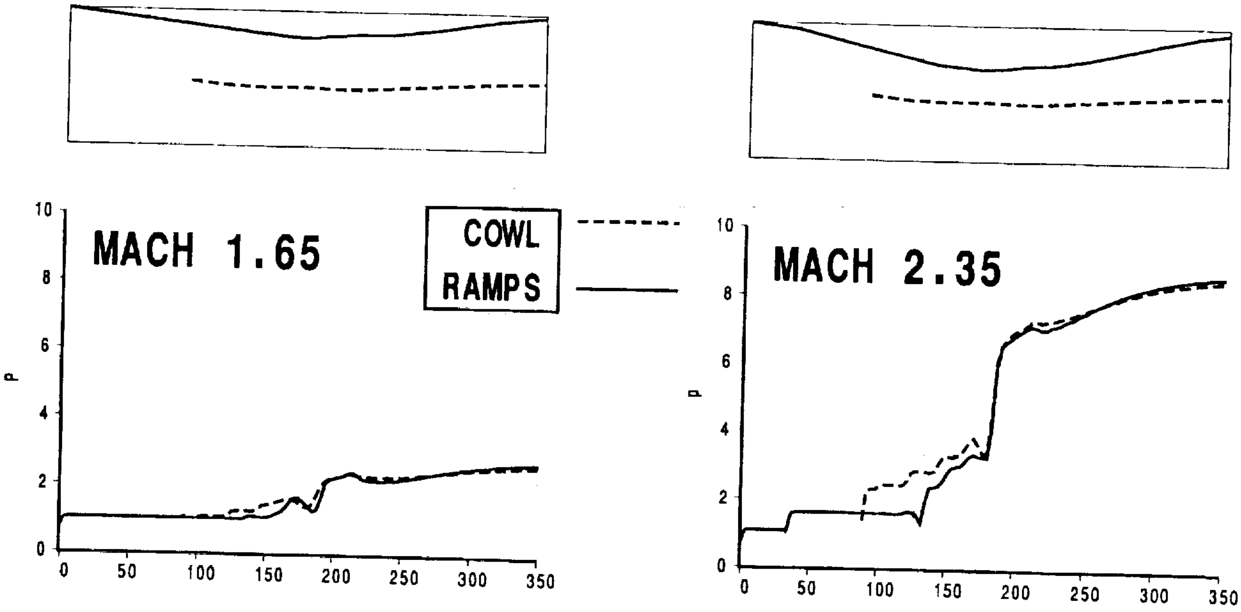


STATIC PRESSURE DISTRIBUTIONS

Ramp and cowl contours and static pressure distributions are shown here for the mixed compression 2D inlet. These curves were extracted from PARC solutions at cruise and at Mach 1.65, the minimum Mach number where started operation is possible. The corresponding Mach contours are shown at top and bottom, respectively, in the previous figure. The pressures are shown in absolute units at the same altitude, clearly indicating the higher inlet pressure ratio at the higher flight Mach number. In actual operation the altitude would vary with Mach number.

STATIC PRESSURE PROFILES

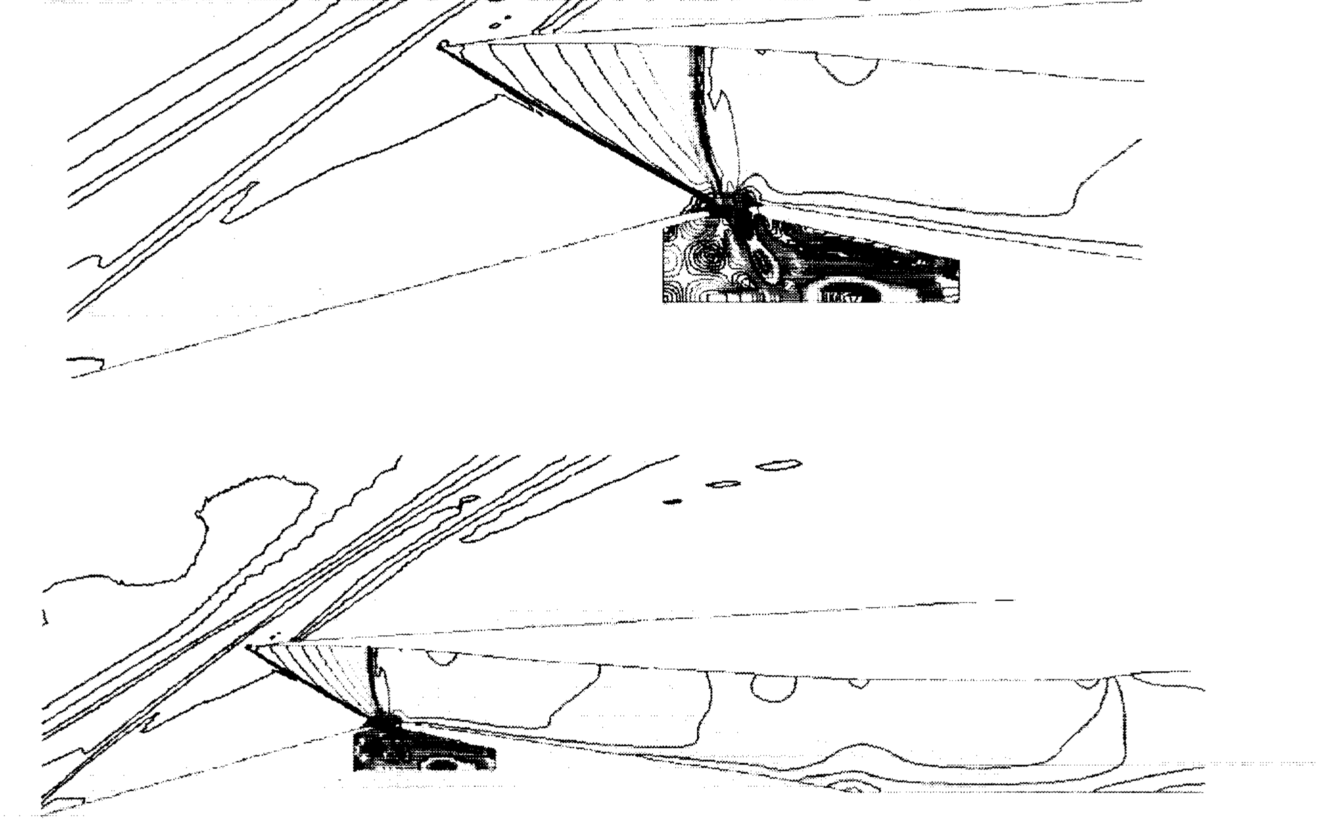
PARC Solution for MC2D Inlet



MIXED COMPRESSION VARIABLE DIAMETER CENTERBODY INLET

The inlet shown here is a Mach 2.35 derivative of the NASA Lewis Mach 2.5 60/40 variable diameter centerbody inlet. A big attraction of such a design is the short supersonic diffuser. The bleed rates computed for this model agree well with the very low requirements established experimentally by NASA. The solution shown here is for Mach 2 flight.

MIXED COMPRESSION VARIABLE DIAMETER CENTERBODY INLET

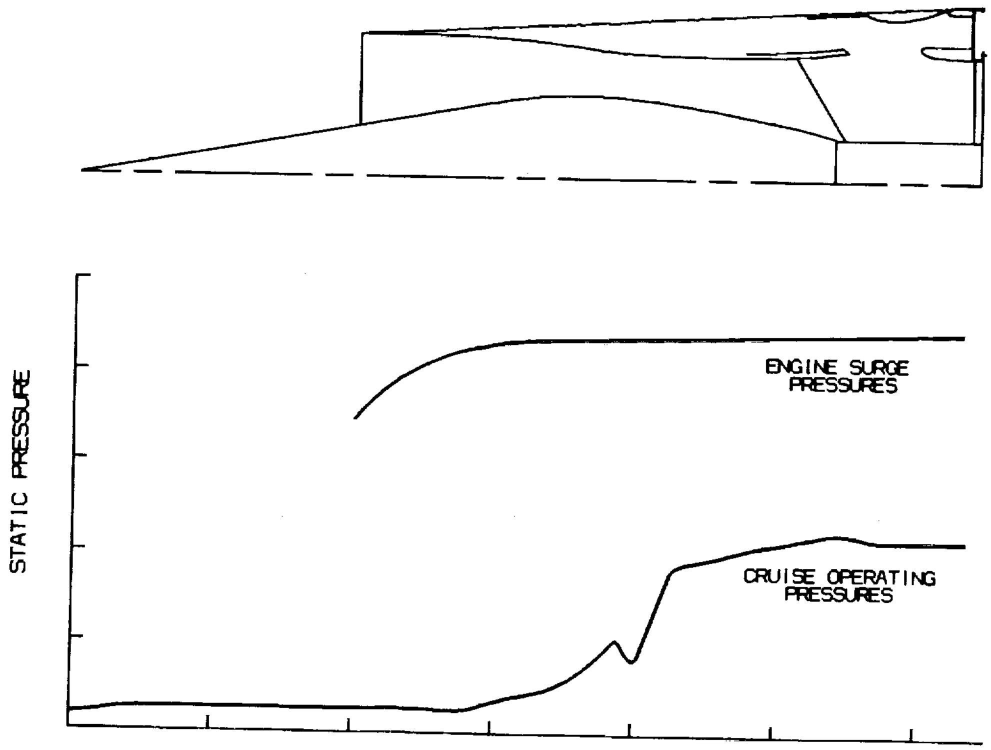


DESIGN LOADS FOR SIZING OF INLET STRUCTURES

The objective of Task 2 of PAIT is to compare the weights of the inlet designs based on the analytical models developed under Task 1. To compute realistic weights, all of the major components of the inlet must be designed and the material thicknesses must be sized for the loads to be encountered in operation.

The chart shows predicted normal operating pressure loads, and hammershock loads (resulting from compressor surge) for the mixed compression axisymmetric translating centerbody inlet. Other analyses were conducted to estimate asymmetric pressure loads, and g–loads resulting from a hard landing. Materials were selected, and material thickness requirements were computed by structures specialists based on the loads data.

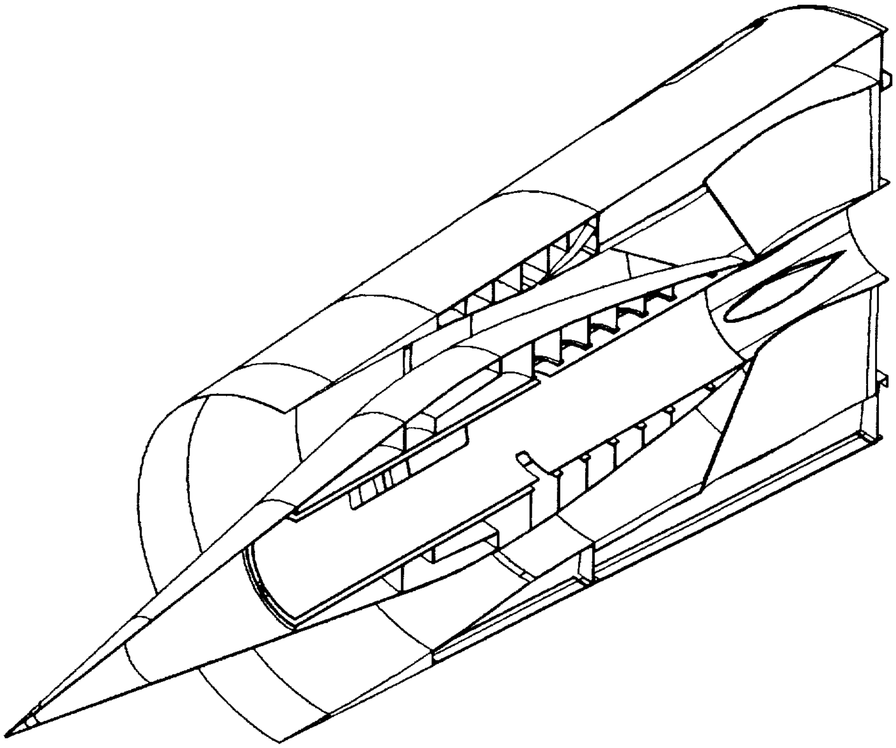
NORMAL AND ENGINE SURGE PRESSURE LOADS



MIXED COMPRESSION TRANSLATING CENTERBODY INLET

This inlet concept traces its ancestry to the NASA Ames P inlet; a contender for the US SST. The picture shows a solids model rendering of the inlet design with the CATIA computer aided design (CAD) system used at Boeing. The inlet components are sized for the loads shown in the previous chart. The CAD system can compute the volume of each component. The volumes, the material densities, and allowances for fasteners, etc. lead to accurate prediction of the final inlet weight.

MIXED COMPRESSION TRANSLATING CENTERBODY INLET



CONCLUDING REMARKS

For propulsion technology the premier issues are airport noise and high altitude emissions. The sources are the nozzle and combustor, respectively. For the inlet the most important issues are associated with integration.

- Integration with the main landing gear: protection from runway FOD;
- integration with the engine: engine/inlet airflow matching, normal shock stability during engine airflow transients;
- integration with the wing: nacelle/wing interference drag, inlet flowfield uniformity.

The inlet development plan includes the following tasks: 1) enhancement of design technology; 2) support of vehicle configuration development; 3) analytical screening of inlet concepts; 4) experimental validation of inlet designs; 5) experimental validation of inlet/engine compatibility; 6) demonstration of propulsion system performance in flight.

CONCLUDING REMARKS

ELEMENTS OF INLET DEVELOPMENT PLAN

- design technology enhancements
- analytical screening of inlet concepts
- experimental validation of inlet designs
- demonstration of inlet/engine compatibility

WORKING WITH NASA AND ENGINE SUPPLIERS

MAJOR ISSUES:

- wing/nacelle interference
- normal shock stability
- engine/inlet airflow match
- landing gear effects

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